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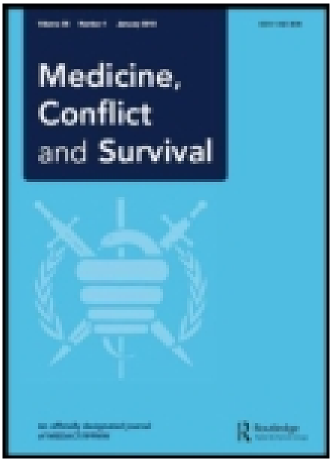

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Uninventing the Bomb?*

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This paper reviews the problem of the abolition of nuclear weapons from the viewpoints of: their roles as products of, and components in, technological systems; the social preconditions underpinning them; and the demands they place on tacit (rather than explicit) knowledge.

KEYWORDS Nuclear-weapon-free world; Tritium; Tacit knowledge; Technological systems; Societal verification

I approach the issue of the abolition of nuclear weapons from the perspective of someone who works in the history and sociology of technology. In this paper I hope to show that some basic, straightforward ideas from this area might provide a useful framework for thinking both about the difficulties of abolishing nuclear weapons and about the opportunities for doing so. I am not going to address the moral, legal, political and military questions of whether we *ought* to abolish nuclear weapons. Rather, what I will focus on is this: supposing we were to decide to abolish nuclear weapons, how might we go about it?

Systems, Social Preconditions and Knowledge

My starting point is to say: let us look at nuclear weapons as a technology. When we think of technology we usually think of artifacts, of things – of washing machines, of computers, of bombs – perhaps together with systematic, explicit, 'engineering science', knowledge of the properties of those things. Yet the history and sociology of technology reveal at least three ways in which this view of technology is impoverished. Each of these ways suggests subtly different approaches to the abolition of nuclear weapons.

First, modern technical artifacts are typically not individual, self-contained things, but parts of technological *systems*. My washing machine, for example, is of no use to me unless plugged in to an electricity supply network. So we need to think about ways in which nuclear weapons can be, as it were, 'unplugged' from their supporting technological systems.

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* Based on a presentation to the MEDACT conference Nuclear Weapons in the Millennium, London, 11 November 1995.

Second, technologies are the outcome not just of physical engineering, but of social engineering – indeed political and economic engineering as well. To make a technology real, you have to move it from an idea on the drawing-board into something that people want, that they feel they need, that they are prepared to pay for, that they feel they cannot live without. (Incidentally, this is of course one of the chief reasons for Britain's economic decline. Historically, Britain has been good at the production of drawing-board ideas, but, at least in the twentieth century, not so good at the later stages of the process.) If we want to abolish nuclear weapons, we have to eliminate the *social preconditions* that make them possible, that enable them to change from drawing-board ideas into apparently necessary weapons.

Third, technological knowledge is never fully explicit; much of it is *tacit.* Tacit knowledge is the kind of knowledge we deploy in being able to ride a bicycle without being able to say precisely how it is that we do so. In the most advanced modern science and technology, tacit knowledge is still present but is – unlike bicycle riding – largely a *local* phenomenon. In other words, some key skills are often not widespread, but are the properties of relatively small groups of people, and are transmitted hand-to-hand and face-to-face.

When one discusses the abolition of nuclear weapons, people often say 'you can't disinvent nuclear weapons'. Even those who want to eliminate these weapons often say that 'the knowledge required to build nuclear weapons can never be eliminated'. It is certainly true that one cannot imagine eliminating the *explicit* knowledge (in nuclear physics and the like) involved in building nuclear weapons. But if *tacit* knowledge is necessary, then that can be lost. Skills, if not practised, decay. If there is no new generation of practitioners to whom tacit knowledge can be passed on hand-to-hand, it may die out altogether. Of course tacit knowledge can be recreated, but that could be quite difficult. In that sense, perhaps nuclear weapons could be not simply abolished, but actually uninvented. There are perhaps respects in which we could, as it were, forget how to make nuclear weapons.

Imagine, by way of analogy, that for some reason all surgery stopped for a couple of generations. Even if every textbook of anatomy and of surgery survived, a fair amount of hands-on trial-and-error learning would be necessary before modern surgical skills could be recreated. I certainly would not wish to be the first patient! Of course, surgery fairly obviously involves tacit knowledge, and it is not immediately clear that this is true of building nuclear weapons – but that is an issue to which I will return.

Systems

Nuclear weapons are both the products of, and components in, technological systems. The former is most obvious in respect to producing the plutonium or enriched uranium they need. These were originally massive technological enterprises. In one year – 1945 – the uranium separation plant at Oak Ridge, Tennessee, consumed more electricity than the whole of Canada produced in the Second World War.[1] Nowadays, there are more efficient ways of enriching uranium, but an obviously essential part of any elimination of nuclear weapons would be the strictest control over the production of plutonium and enriched uranium. That control appears to be feasible technically.

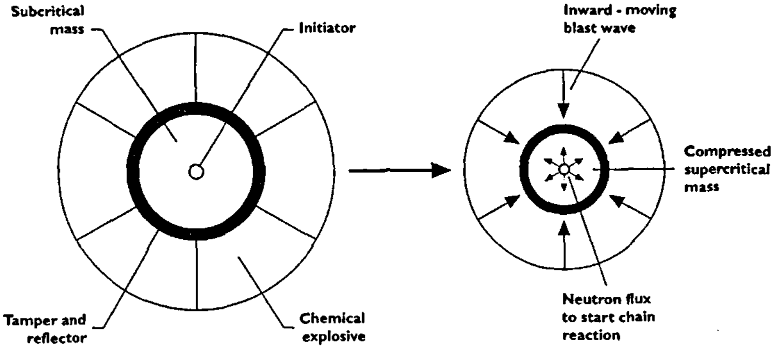
Unfortunately, there is a major problem with the existing world stocks of plutonium and enriched uranium. Housekeeping – even in the United States – has been poor. It is impossible completely to reconcile the production histories of the relevant plants with the known stockpiles: on the face of it, several tens of tonnes have disappeared.[2] It would take an enormous amount of effort before we could have any confidence that all world stocks had been properly accounted for. (One of the reasons why the elimination of nuclear weapons in South Africa was relatively straightforward was that only modest amounts of enriched uranium had been produced, and housekeeping was good enough for the production history of the separation plant to be reconciled with the stockpile).

However, other unusual materials are needed to build nuclear weapons. As far as one can tell from the publicly-available literature, basic nuclear weapons – the kind with which a weapons programme typically begins – have used polonium in their initiators (see Figure 1). The opportunity for control posed by this is that polonium decays quickly (the half-life of polonium-210 is 138 days), so hidden stocks of it would rapidly waste away.

FIGURE 1

ATOMIC OR FISSION BOMB (IMPLOSION DESIGN)

Highly schematic. No attempt has been made to draw to scale. In a 'boosted' fission bomb, gaseous fusion materials are injected into the weapon's core as the chain reaction begins.


Subcritical mass
Initiator
Tamper and reflector
Chemical explosive
Inward - moving blast wave
Compressed supercritical mass
Neutron flux to start chain reaction

Although polonium appears to have been the material of choice in early programmes, there are other means of initiating nuclear explosions, and, in particular, sophisticated weapons do not appear to use polonium (in part because of the inconvenience of its rapid decay).[3] Sophisticated weapons, however, seem typically to be dependent on the hydrogen isotope tritium, both for their initiators and for boosting (enhancement of a fission chain-reaction by the neutrons released in fusion).[4] Tritium, too, decays: more slowly than polonium, but significantly. The half-life of tritium is 12.3 years.

The United States has not been able to produce tritium since 1988, because of safety problems with the reactors at Savannah River, South Carolina. (When one looks at the nuclear weapons production system, especially in the US and former Soviet Union, what is most striking is the extent to which that production system is collapsing of its own accord, so to speak!) Currently the US is re-using tritium from warheads decommissioned under the various arms control agreements, but the Department of Energy calculates that that source will become inadequate by the year 2011. There is fierce debate going on currently in the US as to whether to build a new tritium source.

What happens to a sophisticated nuclear arsenal (say to bombs that might be hidden from away an abolition agreement) if one is able to cut off access to tritium? The only estimate I know of in the publicly available literature is the following from a 1981 Los Alamos report: a cut-off of tritium would mean 'the certain disablement, in approximately a decade, of one half of the [US] nuclear weapons stockpile that uses tritium'.[5] If that were true for other countries' arsenals as well, then control over tritium is a potentially important mechanism in the abolition of nuclear weapons. The quantities of tritium involved are small (the only estimate I have been able to find in the literature suggests a small number of grams per warhead);[6] but world stocks of tritium are far smaller than stocks of plutonium or enriched uranium. However, because tritium decay is measured in decades, not days, it is the sort of issue we must start getting a handle on now, if we are to hope to abolish nuclear weapons early in the next millennium.

The way nuclear bombs are components of technological systems arises because a nuclear device is not a weapon unless it can be delivered to its target. The proverbial suitcase bomb would require substantial skills in miniaturization; aircraft can be intercepted; so militarily the most attractive delivery system has been ballistic missiles. Developing a long-range ballistic missile, and integrating a nuclear weapon into it, are difficult tasks of systems engineering. Although ballistic missiles with relatively short ranges, of the order of 600 kilometres – most commonly the Soviet Scud, or derivatives of it – are now relatively widely diffused world-wide, achieving intercontinental ranges remains a demanding task.

It is unlikely that such a missile could be perfected without (detectable) testing. So control over long-range ballistic missiles – and conceivably over cruise missiles as well – is an important way to make 'break-out' from a nuclear weapons abolition treaty harder.

It is also worth noting that it has been the warhead miniaturization required for missile delivery that has made boosting, and thus tritium, crucial to a sophisticated arsenal. Although greater sophistication in mechanical designs and implosion systems helps, it is, according to one well-placed US observer, boosting that is 'mainly responsible for the remarkable 100-fold increase in the efficiency of fission weapons' since 1945.[7]

The Social Preconditions of Nuclear Weapons

Is it possible to eliminate the social preconditions that make nuclear weapons seem necessary? One precondition is the possibility of major war between industrialized nations. So long as that kind of war seems possible, it will be very difficult to abolish nuclear weapons with any confidence of permanence, because of fears that in the event of such a war one or other party would seek to re-arm with nuclear weapons, and, being industrialized, would have the capacity to do so.

Essentially, what we must do is to bring into being a world in which to settle disputes by war will be seen as patently irrational, because the costs of even quick and complete victory clearly outweigh any benefits. Is such a world wholly utopian? I think not. Technological change is already pushing us towards an inter-connected world, and it has also created, in the advanced industrialized countries, a mutual vulnerability, even to conventional weapons, far greater than existed in 1945. Imagine, for example, the consequences of a bombing raid (using conventional bombs) on a fuelled-up nuclear power station or nuclear reprocessing plant!

Consider what has happened in Europe over the last half-century. We no longer fear war between, for example, France and Germany. (The current hysteria in British politics about Europe shows an extraordinary blindness to this remarkable historical achievement.) That outcome is only partly the result of experience of the costs of war: it has also been brought about by the mutual benefits of interconnectedness and interdependence. Note that these benefits must be mutual: patterns of trade that systematically impoverish one partner while enriching the other are clearly not going to eliminate the possibility of war.

The elimination of the possibility of major war between industrialized nations is, of course, an ambitious goal, and it is also worth thinking about more modest social changes that would help make the abolition of nuclear weapons more feasible. A lot of these have to do with secrecy, and this is where I find Professor Rotblat's work on 'societal verification' very valuable.[8] There has been enormous progress in satellite surveillance: one can do some pretty remarkable things now, such as monitoring whether bomb-making materials are being produced by measuring, from space, fluctuations in the heat output of nuclear reactors and even changes in vegetation patterns. But satellite surveillance is never likely to be watertight. So one needs to encourage a world in which citizens are able, and willing, to report violations of arms control agreements by their own governments: that is the idea of 'societal verification'. It ties the abolition of nuclear weapons to fostering democracy and human rights – in the Third World, yes; but there are things we might with to attend to at home as well, such as the lack of a Freedom of Information Act in Britain.

Tacit, Local Knowledge

What about 'forgetting' how to build nuclear weapons by losing the requisite tacit knowledge? It is easy to think that all you need in order to be able to build a nuclear weapon is explicit knowledge, the kind of knowledge you can find in physics textbooks. But that is not so.[9] Reading the various histories of the Manhattan Project, I have been struck by the initial confidence there was that, once the necessary plutonium and enriched uranium had ben produced, actually designing the bomb – the job of the Los Alamos laboratory – would be straightforward. Edward Teller recalls being advised by future Nobel laureate Eugene Wigner not to join Los Alamos because its task – designing the atomic bomb – would be too easy. The Director of Los Alamos, Robert Oppenheimer, originally planned the laboratory to be no bigger than the physics department of a large university. Even the site, 7,000 feet up in the New Mexico mountains, reflected not just the need for secrecy but also the feeling that this was going to be a pretty small-scale activity.

However, the job of Los Alamos turned out to be far from straightforward. Designing and building the first two atomic bombs, Little Boy and Fat Man, ended up absorbing the efforts of thousands of skilled staff. A lot of what was at issue was not nuclear physics, but the technological practicalities of turning an idea into an actual working bomb.

Of course, once that job of design is done, it is written down: in diagrams, measurements, descriptions. *Apparently*, it becomes explicit knowledge, the sort of knowledge you store permanently and can pass on. But was it entirely explicit? One of the Los Alamos designs – for the plutonium implosion weapon, Fat Man (the Nagasaki bomb) – was passed on, by the Los Alamos physicist Klaus Fuchs. In June 1945, Fuchs gave detailed documents on the design of Fat Man to an agent of Soviet intelligence. At the end of the war, Fuchs – who was part of the British delegation at Los Alamos – also violated the agreement between the UK and US by removing documents from Los Alamos. Struck by how much Fuchs could recall from the Los Alamos years, Fuchs's colleagues in the later British nuclear weapons programme thought he had a remarkable memory![10]

Both the Soviet Union and Britain started their nuclear weapons programmes by attempting to copy Fat Man, and the Soviets were doing it on the basis of explicit knowledge alone – essentially the documents Fuchs passed to them. What the histories of the Soviet and the British programmes show – and well-documented histories of both are now in the public domain – is that while this explicit knowledge helped, it was by no means sufficient.[10–12] Many of the technological skills that had been learnt, by trial-and-error, in the Manhattan project, had to be slowly, painfully, relearnt. Just like Los Alamos, both Aldermaston and the Soviet laboratory, Arzamas-16, had to grow to be far bigger than had originally been planned.

Indeed, one thing that is striking about the history of nuclear proliferation (see Table 1) is that all the efforts to build an atomic bomb, subsequent to the Manhattan Project, have actually been slower than it.

Of course, this was in part because the US, even as long ago as the 1940s, had larger resources to devote to the task than any subsequent nuclear weapons programme has had. But I think it is also because tacit knowledge had to be learnt afresh by the inevitably slow process of trial and error.

(Incidentally, you may notice from the table that this appears to be the case only for the atomic bomb, not for the hydrogen bomb. Tacit knowledge seems to play a less important role in the hydrogen bomb. Fortunately, there is no known way of making a hydrogen bomb without first having an atomic bomb.)

The fact that some of the knowledge involved in designing and making nuclear weapons is tacit is of considerable importance. Some of that knowledge is already being lost – now, today. In the US, the Department of Energy is devoting several million dollars a year to what it calls the Knowledge Preservation Project, which is doing things like in-depth interviews with retired nuclear weapons designers. It is as if one stopped surgery, and frantically interviewed all the surviving surgeons before they died! It will help preserve knowledge, but if I am right about tacit knowledge the Knowledge Preservation Project cannot succeed completely in its task. That means that, even with the best archive, recreating a nuclear arsenal, after a sufficiently long hiatus, would be significantly more difficult than is suggested by glib assertions about the impossibility of uninventing nuclear weapons.

Conclusion

The Bad News

I do not want to be over-optimistic. None of the mechanisms for the abolition of nuclear weapons discussed here is watertight. It is hard to make control over materials watertight. As for social preconditions, we social

TABLE 1

APPROXIMATE CHRONOLOGIES OF SUCCESSFUL NUCLEAR EXPLOSIVE DEVELOPMENT PROGRAMMES

	Start of nuclear weapons development programme	Date of first *atomic* test explosion (*) or weapons (†)	Date of first thermonuclear test explosion (*) or weapon (†)	Significant personal contact with previously successful weapons design team?	Began with attempt to copy previous design?
US	1942	1945*	1952*	no	no
USSR	1945	1949*	1953*	no	yes
UK	1947	1952*	1957*	yes	yes
France	1955	1960*	1968*	no	?
China	c. 1955	1964*	1967*	no	no
Israel	c. 1957 (?)	c. 1968 (?)†	?†	?	?
India	c. 1964	1974*		?	?
South Africa	1971	1979†		?	?
Pakistan	c. 1974 (?)	?†		?	yes (?)

U=uranium; Pu=plutonium; imp.=implosion. India maintains its 1974 explosion to have been of a peaceful nuclear device. India, Israel, and Pakistan are not declared nuclear weapons states, but expert consensus is that they either possess, or could quickly assemble, nuclear weapons. India, Pakistan, and South Africa are not believed to have developed thermonuclear weapons; it is not clear whether Israel has done so.

Sources: see MacKenzie D, Spinardi G. Tacit knowledge, weapons design, and the uninvention of nuclear weapons. *American Journal of Sociology* 1995; **101**: 44–99 (reference 9).

scientists cannot make predictions with the confidence that physicists can, so it would take some time to become confident that the social preconditions for nuclear weapons have really been eliminated. If all one is trying to do is to build a large, crude nuclear weapon, then the demand for tacit knowledge is not overwhelming.

The Good News

The good news, in contrast, is in part simply the diversity of available mechanisms. Perhaps the abolition of nuclear weapons is like one of those situations in medicine where no one medication is sufficient, but several in combination can do the job. Furthermore, there is some evidence that the *interactions* between the phenomena I have been discussing are benign, from the viewpoint of the abolition of nuclear weapons.

For example, I have noted that militarily the most attractive delivery vehicle will usually be a ballistic missile. However, even building a nuclear warhead for a Scud missile (the task on which Iraq appears to have been engaged) is significantly more demanding than building a large, crude nuclear weapon. The payload of a Scud is around 1,000 kilograms, while the now declassified figure for the weight of the Hiroshima bomb is 4,000 kilograms, and the implosion weapon Fat Man, the Nagasaki bomb, appears to have been somewhat heavier. Only in 1952 did a nuclear weapon weighing less than 1,000 kilograms enter the US arsenal.[3] So a Scud nuclear warhead has to improve significantly on the Manhattan Project designs: the need for designers' skills is not trivial. The 'system' demands interact with the 'tacit knowledge' demands, and do so beneficially from the viewpoint of abolishing nuclear weapons.

But even interactions such as this do not add up to a watertight case. Personally, I feel that we have to approach the abolition of nuclear weapons as a process: we do not know, and should not pretend to know, at this point in time, the solution to all the problems it may throw up.[13] Paradoxically, though, the very fact that the abolition of nuclear weapons involves problems to which we do not yet know the solution may be an attraction of abolition. For example, if governments were sufficiently imaginative, they might find that their nuclear weapons laboratories (which generally now have a lot less to do than they once had) contain people who would love to be set loose on some of these problems. I was very struck by the following comment by a US nuclear weapons designer, reported in the *Bulletin of the Atomic Scientists*: 'Zero in 2005. I can get enthused by that project. What a neat way to cap off your career.'[14]

2005 is an unrealistic time-scale within which to complete the elimination of nuclear weapons. But if their abolition can be pondered in a nuclear weapons laboratory, perhaps the rest of us need to take it seriously too.

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